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THE USE OF SELF-TUNING LOOPS FOR GUARANTEEING THE QUASI-OPTIMAL--ETC(U)
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THE USE OF SELF-TUNING LOOPS FOR GUARANTEEING THE QUASI-OPTIMAL CHARACTERISTICS OF SERVO SYSTEMS OF COMBINED CONTROL

by

B.V. Novoselov

FOREIGN TECHNOLOGY DIVISION

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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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THE USE OF SELF-TUNING LOOPS FOR GUARANTEEING THE QUASI-OPTIMAL CHARACTERISTICS OF SERVO SYSTEMS OF COMBINED CONTROL.

B. V. Novoselov.

I. General considerations.

The use/application of the combined control in the servo systems (Fig. 1) makes it possible to attain the full/total/complete or partial invariance of value [illegible] from input effect (VV) [illegible]. In Fig. 1 $K_1(p)$, $K_2(p)$ - the transfer functions of components/links the servo systems of the combined control (SSKR); n(p), [illegible] - the conditional statements of interferences; φ(p) - the transfer function of compensator (KU).

From the theory and the practice of SSKR it is known:

1. In the absence of interferences n(t), [illegible] and with satisfaction of the condition

$$\varphi(p) = \frac{1}{K_2(p)} \quad (1.1)$$

is ensured full/total/complete invariance $H(t)$ relatively $H_1(t)$.

2. If it is provided (1.1), then interference n(t) completely passes to entire frequency band into error of SSKR. For guaranteeing the high accuracy of SSKR it is necessary to filter out n(t) from $H_1(t)$. Virtually this is possible only in the case of nonintersecting spectra $H_1(t)$ and n(t) [1].

3. For decreasing effect $U'_v(t)$ on error of SSKR should be chosen factor of amplification of component/link $K_2(p)$ sufficiently to small ones.

4. Presence of polynomial in denominator of transfer function of KU $\varphi(p)$ leads to steep/abrupt decay in frequency characteristic of locked SSKR after cutoff frequency. On the basis of the conditions of high accuracy and operating speed of SSKR during the final adjustment of useful VV, it is desirable to ensure the low values, and from the point of view of high freedom from interference - increased values of the coefficients of the polynomial of denominator $\varphi(p)$.

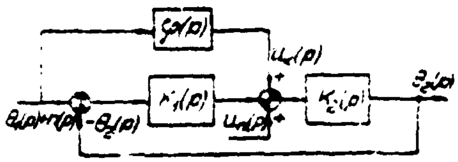

Fig. 1. Block diagram of SSKR.

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5. In limits of physical feasibility φ(p) SSKR possesses increased oscillation property with change of VV in comparison with system without KU. This is explained by the following. If without the introduction/input of KU with VV $\Theta_1(t) = 1(t)$ at the output of system had $\Theta_2(t) = h(t)$, that during the introduction/input to input $K_1(p)$ KU φ(p)=φp at the input of SSKR operates equivalent VV

$$\Theta_{1э}(t) = 1(t) + \varphi\delta(t), \qquad (2)$$

while at the output of SSKR $\Theta_2(t)$ it is expressed

$$\Theta_{2э}(t) = h(t) + \varphi \frac{d\Theta_2(t)}{dt} = h(t) + \varphi\omega(t). \qquad (3)$$

where δ(t) - impulse function; h(t) - transient function; ω(t) - weighing function.

It is known [2] which ω(t) has at least one extremum even when some real roots alone of the characteristic equation of locked SSKR are present.

Frequently in practice of SSKR operate VV of the form

$$\vartheta_1(t) = \Theta_1(t) + \Delta\Theta_1(t) + n(t), \qquad (1.1)$$

where $\Theta_1(t)$ - standard useful VV; $\Delta\dot{\Theta}_1(t)$ - unfavorable VV (change of useful VV with the high accelerations); n(t) the stationary random function of time (interference).

In this case is required to ensure a maximally possible accuracy during final adjustment $\Theta_1(t)$ of the type

$\Theta_1(t) = \Omega_1 t$, $\Theta_1(t) = \frac{\varepsilon_1 t^2}{2}$; $\Theta_1(t) = \Theta_{1m}\sin\omega t$ (Ω_1 the speed, ε_1 - acceleration at the input of SSKR), high freedom from interference of SSKR and qualitative free transient process and transient process during final adjustment $\Delta\Theta_1(t)$ with the physically realizable components/links of main circuit of SSKR and KU.

In the present work based on specific example is examined the effect of the parameters of KU on the quality of work of SSKR and is shown the need for input of the self-tuning loops (KSN) of the compensating signals (KS) for guaranteeing the quasi-optimal characteristics of SSKR into different modes of operation of SSKR.

II. Analysis of the effect of the parameters of KU on the quality of SSKR.

Let as a result of synthesis on the quality of free transient

process be obtained the transfer function of the extended system without KU

$$K(p) = K_1(p)K_2(p) = \frac{K(1+T_2p)}{p(1+T_1p)(1+T_3p)} = \frac{158(1+0{,}289p)}{p(1+1{,}2p)(1+0{,}0138p)} \quad (2.1)$$

For guaranteeing the full/total/complete invariance with $K_1(p)=1$ it is necessary to ensure

$$\varphi(p) = \frac{1}{K(p)} = \frac{p(1+T_1p)(1+T_3p)}{K(1+T_2p)}. \quad (2.2)$$

In practice is usually sufficient to compensate for static $\Theta_{ст}$, kinetic Θ_v and dynamic Θ_a of error. Since the system in question possesses first-order astaticism, then $\Theta_{ст} = 0$. For compensation Θ_v, Θ_a it is necessary to fulfill KU with the transfer function

$$\varphi(p) = \frac{T_4p}{1+T_5p}.$$

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Transfer function of locked SSKR relative to $\Theta_1(p)$

$$\Phi(p) = \frac{K(p)[1+\varphi(p)]}{1+K(p)} = \frac{d_3p^3+d_2p^2+d_1p+d_0}{a_4p^4+a_3p^3+a_2p^2+a_1p+a_0}, \quad (2.3)$$

where

$d_0 = 45.68\ K_{1z}T_4$; $d_1 = 158K_{1z}T_4 + 45{,}68T_5 + 45.68K_{1z}$);
$d_2 = 158T_5 + 158K_{1z} + 45{,}68$; $d_3 = 158$; $a_0 = 0{,}0165T_5$;
$a_1 = 0{,}0165 + 1{,}21T_5$; $a_2 = 1.21 + 46{,}68T_5$;
$a_3 = 46.68 + 158T_5$; $a_4 = 158$.

Transfer function of error relatively $\Theta_1(p)$

$$\Phi_\theta(p) = 1 - \Phi(p) = \frac{a_0p^4 + (a_1-d_0)p^3 + (a_2-d_1)p^2 + (a_3-d_2)p}{a_0p^4 + a_1p^3 + a_2p^2 + a_3p + a_4}. \quad (2.5)$$

With those slowly changing $\theta_{in}(t)$ is correct the expansion of the rational-linear function $\Phi_\theta(p)$ in the Maclaurin series

$$\Phi_\theta(p) = \Phi_\theta(0) + \frac{p}{1!}\Phi_\theta'(0) + \frac{p^2}{2!}\Phi_\theta''(0) + \ldots + \frac{p^n}{n!}\Phi_\theta^{n}(0) + \ldots =$$
$$= C_0 + C_1p + C_2p^2 + C_3p^3 + \ldots + C_np^n + \ldots \quad (2.6)$$

where C_0, ... C_n - the error coefficients, determined in dependences [3]:

$$\left.\begin{aligned}
C_0 &= \lim_{p\to 0}\Phi_\theta(p),\\
C_1 &= \lim_{p\to 0}\frac{1}{p}[\Phi_\theta(p) - C_0],\\
C_2 &= \lim_{p\to 0}\frac{1}{p^2}[\Phi_\theta(p) - C_0 - C_1p],\\
&\ldots\ldots\ldots\ldots\ldots\ldots\\
C_n &= \lim_{p\to 0}\frac{1}{p^n}\left[\Phi_\theta(p) - \sum_{i=0}^{n-1}C_ip^i\right].
\end{aligned}\right| \quad (2.7)$$

Work [3] shows the validity of expansion (2.6) for sinusoidal VV with the frequencies, which lie at the range from zero to the cutoff frequency of frequency characteristic of SSKR, and for exponential VV, when time constant of VV is more than the time constant of reaction of SSKR to the unit step.

For guarantee $\theta_x=0$, $\theta_a=0$ it is necessary to satisfy the condition

$$C_1=0, \; C_2=0. \quad (2.8)$$

Simultaneously fulfillment $C_1=0$, $C_2=0$ requires the guarantee of the conditions

$$K_{1x} = K_1 \frac{T_4}{T_6} = \frac{1}{158}.$$

$$K_1 = \frac{T_5 + 0{,}925}{158\,T_5}. \qquad (2.9)$$

Fig. 2 depicts graphs $K_1=f(T_5)$, $T_4=f(T_5)$, $\alpha=f(T_5)$ whose points correspond to the parameters of KU, which ensures $\Theta_s=0$, $\Theta_n=0$.

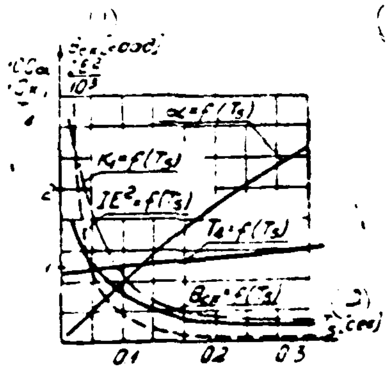

Fig. 2. Design charts of the parameters of SSKR.

Key: (1). [deg]. (2). s.

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According to (1.4), (1.5) the introduction/input of KU increases the oscillation property of system during final adjustment ΔH. Therefore it is necessary to investigate the dependence of the integral quadratic evaluation/estimate

$$IE^2 = \int_0^\infty \theta_z^2 dt$$

on the parameters of KU.

For a rational-linear function of form (2.4) is convenient IE^2 to determine on dependence [4]

$$IE^2 = \frac{\Delta G}{2a_0 \Delta H}, \qquad (2.10)$$

Where

$$\Delta H = \begin{vmatrix} a_1 & a_0 & 0 & . & . & 0 & 0 \\ a_3 & a_2 & a_1 & a_0 & 0 & 0 & 0 \\ a_5 & a_4 & a_3 & a_2 & a_1 & a_0 & 0 \\ . & . & . & a_4 & . & . & . \\ & & & & \vdots & & \\ 0 & . & . & . & . & . & a_n \end{vmatrix} \qquad (2.11)$$

$$\Delta G = \begin{vmatrix} d_0^2 & a_0 & 0 & . & 0 \\ -d_1^2 - 2d_0d_2 & a_2 & a_1 & . & 0 \\ d_2^2 - 2d_1d_3 + 2d_0d_4 & a_4 & a_3 & . & 0 \\ \vdots & . & . & & \\ (-1)^{k-1}d_{k-1}^2 - 2\sum (-1)^{[illegible]} d_{k-[illegible]}d_{k-[illegible]} & . & . & . & . \\ \vdots & . & . & . & . \\ (-1)^{n-1}d_{n-1}^2 & . & . & . & a_n \end{vmatrix} \qquad (2.11)$$

After the substitution of numerical values and series/row of conversions we have

$$IE^2 = \frac{1{,}[illegible]36\cdot10^{6}T_s^{4} - 4{,}[illegible]6\cdot10^{3}T_s^{3} + 1{,}34\cdot10\,T_s^{2} - 2{,}3[illegible]\cdot10^{4}T_s - 61[illegible]}{4{,}4[illegible]\,T_s^{[illegible]} + [illegible]\,T_s^{[illegible]} + 142T_s^{2} + [illegible]\,T_s} \qquad (2.12)$$

As it follows from (2.12), IE^2 is function T_s. The optimum value of T_s it would be possible to determine, on the basis of the condition of equality to zero partial derivative

$$\frac{\partial IE^2}{\partial T_s} = 0, \qquad 2.13$$

but in this case it would be necessary to solve the equation of the 6th degree, which is too labor-consuming.

Fig. 2 presents dependence $IE^2 = f(T_s)$ for the values of the parameters of KU, those lying/horizontal on the trajectories satisfying the conditions, which ensure $\sum$.

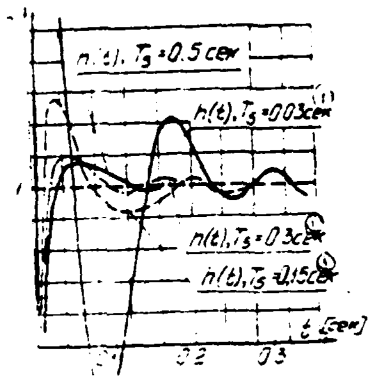

Fig. 3. Calculated time-response characteristics.

Key: (1). s.

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In Fig. 3. are represented time-response characteristics [illegible] when [illegible] for the variety of combinations of the parameters of KU, which ensure $\sum C_i = 0$

a	T_3 = 0,03,	T_4 = 0,955,	K_1 = [illegible]	x [illegible]
b	T_3 = 0,15,	T_4 = 1,075,	K_1 = 0,045,	x = 0,14[illegible]
c	T_3 = 0,3,	T_4 = 1,225,	K_1 = 0,0258,	x = 0,245
d	T_3 = 0,5,	T_4 = 1,425,	K_1 = 0,018,	x = 0,351.

If [illegible] and n(t) is correlation not depended, then mutual spectral density is equal to zero, and the average/mean value of the

square of error from interference n(t) is expressed

$$\overline{\Theta_n^2(t)} = \frac{1}{\pi}\int_0^\infty |\Phi(j\omega)|^2 G_n(\omega)\, d\omega, \qquad (2.14)$$

where $G_n(\omega)$ - the spectral density of interference n(t).

When $\Phi(j\omega)$ and $G_n(\omega)$ are the rational-linear functions of frequency, $\overline{\Theta_n^2(t)}$ it is possible to compute in the form of explicit function of the parameters of system similarly to computation IE², using the tables of integrals, represented in [5].

When $G_n(\omega) = N^2 = \text{const}$ $\overline{\Theta_n^2(t)}$ it is expressed

$$\overline{\Theta_n^2(t)} = \frac{1}{2\pi}\int_{-\infty}^{\infty} \frac{(d_0 p^3 - d_1 p^2 + d_2 p - d_3)N^2}{(a_0 p^4 - a_1 p^3 + a_2 p^2 - a_3 p + a_4)^2}\, dp =$$

$$= \frac{N^2}{2\pi}\int_{-\infty}^{\infty} \frac{L(-p)L(p)}{M(-p)M(p)}\, dp, \qquad (2.15)$$

where

$$L(p) = d_0 p^3 + d_1 p^2 + d_2 p + d_3,$$

$$M(p) = a_0 p^4 + a_1 p^3 + a_2 p^2 + a_3 p + a_4.$$

According to [5] for the present instance

$$\overline{\Theta_n^2(t)} = N^2 \frac{d_3^2(-a_0 a_3 + a_1 a_2) + (d_2^2 - 2d_1 d_3)a_0 a_1 a_4 + (d_1^2 - 2d_0 d_2)a_0 a_3 a_4 + d_0^2(-a_1 a_4^2 + a_2 a_3 a_4)}{2a_0 a_4(-a_0 a_3^2 - a_1^2 a_4 + a_1 a_2 a_3)} \qquad (2.16)$$

The rms error, caused by interference, is expressed

$$\Theta_{n} = \sqrt{\overline{\Theta_n^2(t)}}. \qquad (2.17)$$

Fig. 2 presents dependence $H_{cx}=f(T_3)$.From the analysis of the results of the produced calculation it follows:

1. The compensation for conservative values H_{cx}, H_3 can be realized during different combinations of the parameters of KU, but satisfying conditions (2.9).

2. Oscillation property and freedom from interference of SSKR to a considerable degree depend on value of T_3.

3. Selection of stationary parameters of KU, ensuring simultaneously optimum characteristics of SSKR at final adjustment $H_1(t)$ of that mixed with n(t) and at final adjustment $\Delta H(t)$ is virtually impossible. Appears the need of changing the parameters of KU as the function of VV by introduction/input of KSN.

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III. On the introduction/input of KSN to SSKR.

As it follows from (1.6), at the input of SSKR in the general case operates the sum of the signals: useful VV $H_1(t)$ unfavorable VV $\Delta H(t)$, interference n(t). According to requirements $H_{cm}=0$, $H_c=0$, $H_3=0$ stated in Section 1 during final adjustment $H_1(t)$ of the type

$\Theta_{1r}(t) = \Omega_1 t$;

$$\Theta_{1r}(t) = \frac{\varepsilon_1 t^2}{2}; \quad \Theta_{1r}(t) = \Theta_{1m} \sin \omega t$$

(where ω - comparatively low frequency). Consequently, dynamic error of SSKR during final adjustment $\Theta_{1r}(t) - n(t)$ is caused only by action n(t). In the transient modes/conditions during final adjustment $\Delta\Theta_1(t)$ the error amounts to high values. From section II it follows that during final adjustment $\Theta_{1r}(t)$ it is desirable to have the low values of T_3, and under effect n(t) and $\Delta\Theta_1(t)$ the high values T_3.

In the diagram in Fig. 4a KSN1 ensures the maintenance of the relationship/ratio

$$K_{12} = K_1 \frac{T_4}{T_3} = \frac{1}{\sqrt{3}}.$$

and KSN2 ensures change T_3 in the linear law as a function of error of SSKR.

In the diagram in Fig. 4b signal of the assigning tachogenerator (TG) through the potentiometer of tuning (PN) enters the differentiator (DK) and KSN, which consists of two filters F1, F2 and two phase discriminators FD1, FD2. Under effect $\Theta_{1r}(t)$ T_3 it is reduced, while under effect $\Delta\Theta_1$ or presence n(t) T_3 it increases with the corresponding change K_1, T_4.

Construction of KSN depending on the requirements, presented to SSKR, can be other. For example, at the moments of the time when

operate [illegible] SSKR behaves as narrow-band system, and under effect [illegible] passband of SSKR is expanded by decrease of T_1.

Conclusion/output.

Accuracy, oscillation property and freedom from interference of SSKR to a considerable extent depend on the parameters of KU. The selection of the stationary parameters of KU, ensuring quasi-optimal characteristics of SSKR in different operating modes, is virtually impossible.

Is shown the advisability of using the self-tuning loops for guaranteeing the quasi-optimal characteristics of SSKR.

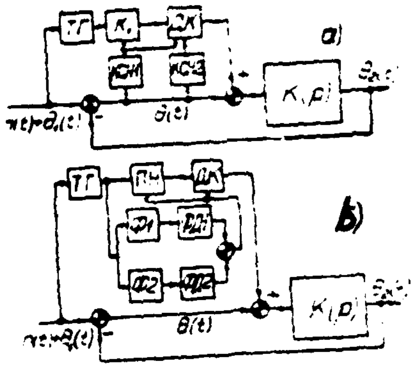

Fig. 4. Diagrams of SSKR with KSN KS.

REFERENCES

[illegible]
[illegible] Электромеханика № [illegible]